UNSIGNALLED DELAY OF REINFORCEMENT IN VARIABLE-INTERVAL SCHEDULES

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Three pigeons responded on several tandem variable-interval fixed-time schedules in which the value of the fixed-time component was varied to assess the effects of different unsignalled delays of reinforcement. Actual (obtained) delays between the last key peck in an interval and reinforcement were consistently shorter than the nominal (programmed) delay. When nominal delays were relatively short, response rates were higher during the delay condition than during the corresponding nondelay condition. At longer nominal delay intervals, response rates decreased monotonically with increasing delays. The results were consistent with those obtained from delay-of-reinforcement procedures that impose either a stimulus change (signal) or a no-response requirement during the delay interval.

Key words: delay of reinforcement, tandem schedules, variable-interval schedules, fixed-time schedules, key peck, pigeons

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Delay-of-reinforcement is a generic term that describes a variety of experimental procedures, all of which involve the interpolation of a period of time between the required response and the occurrence of reinforcement. In perhaps the most widely studied procedure, a stimulus is presented during the interval between the response and reinforcement. Several studies have found an inverse relation between response rate and length of delay when the delay interval is signalled by darkening the chamber (e.g., Chung, 1965; Chung and Herrnstein, 1967). This signalled delay-of-reinforcement procedure may be viewed as a two-component chained schedule with response-independent reinforcement in the terminal component (cf. Ferster and Skinner, 1957, p. 684). An inverse

relation also exists between responding in the initial component of chained variable-interval variable-interval (chain VI VI) schedules and the average interreinforcement interval in the terminal component (e.g., Kelleher and Gollub, 1962).

Other experiments have used tandem schedules to study delay of reinforcement. With such schedules, behavioral effects of changes in response-reinforcer contiguity can be examined without the confounding effects of the discriminative stimulus provided in signalled delay procedures. In one procedure, specific response requirements are programmed in the terminal component of the tandem schedule. Skinner (1938, p. 139) and Azzi, Fix, Keller, and Rocha e Silva (1964) employed a differential-reinforcement-of-other-behavior (DRO) requirement in the terminal component, that is, the onset and continuation of the delay interval was unsignalled and each response during the terminal component extended the delay interval. Generally, the results were qualitatively similar to those with chained schedule procedures: response rates decreased with increasing delay requirements. However, a difficulty in interpreting these results is that delay of reinforcement effects are confounded with effects of the DRO contingency which, by associating the reinforcer with pauses in responding, control lower rates in the initial compo-

nent of the tandem schedule. Further, insofar as responses do occur in the delay component under these conditions, there also could be a reduction of the overall rate of reinforcement.

Tandem schedules with response-independent reinforcement rather than a DRO requirement in the terminal component permit an analysis of reinforcement delay without association of nonresponding with the reinforcer. Dews (1960) compared performance under tandem fixed-ratio 1 DRO (*tand* FR 1 DRO) and tand FR 1 fixed-time (*tand* FR 1 FT) schedules. In the latter procedure, reinforcement occurred independently of responding in the terminal component. By comparison with the FT schedule, the DRO contingency in the terminal component reduced responding in the initial component. However, since FR 1 baseline performance was not reported, these effects cannot be assessed relative to a nondelayed reinforcement condition. Further, the contribution of changes in reinforcement frequency to these findings was not evaluated. Sizemore and Lattal (1977) found that a tandem variable-interval fixed-time schedule (tand VI FT) produced large decreases in responding relative to behavior maintained by a VI 60-sec schedule. However, only one FT value (3-sec) was systematically investigated. Williams (1976) also found that nominal (programmed) delays of ≥ 3 sec included on a simple VI schedule reduced responding relative to a nondelayed VI baseline condition, but no systematic relation was found between the rate of response and the nominal delay value. These findings cannot be evaluated fully because actual, *i.e.*, obtained, delays between the last key-peck response and reinforcement were not assessed. Also, the delay was added at the end of each interval so that resulting changes in reinforcement frequency during the delay condition could lower response rates independently of the delay-of-reinforcement manipulation. The present experiment examined the relation between responding and nominal and obtained delays in tandem VI FT schedules in an attempt to clarify the relation between response-reinforcer temporal contiguity and rate of response. Reinforcement frequency between the nondelayed and delayed reinforcement procedures was held constant by preceding each delay condition with a VI schedule of equal value to the reinforcement frequency during the subsequent delay condition.

METHOD

Subjects

Three White Carneaux pigeons were maintained at 80% (±15 g) of free-feeding weights. Two were experimentally naive and one (87) had experience with various schedules of positive reinforcement.

Apparatus

A Grason-Stadler operant conditioning chamber with a work area of 33 by 35 by 35 cm was used. A 2.5-cm response key, transilluminated by a red light at all times except during reinforcement, was mounted in the center of the panel, 23 cm above the floor. A force of approximately 0.10 N was required to operate the key. General illumination was provided by two 6-W light bulbs mounted behind a white plastic disc, 4 cm in diameter, located in the upper right-hand corner of the work panel. The response key was 13 cm above a 5- by 5-cm opening in the chamber wall in which a hopper filled with mixed grain was made available. The reinforcer was a 3-sec period of access to the grain hopper, during which time the aperture was illuminated. Extraneous sounds were masked by the continuous presentation of 90-dB white noise. Electromechanical programming and recording equipment were in an adjacent room.

Procedure

The naive subjects were trained to eat from the food hopper and then hand-shaped to peck the response key. Approximately 25 reinforcers were delivered according to an FR 1 schedule. For each bird, the schedule then was changed over several sessions to VI 61-sec or VI 70-sec. The sequence of schedules and numbers of sessions for each are shown in Table 1. Changes in conditions were made only when the behavior of a subject was stable on each schedule. Stability was defined by six consecutive sessions in which the mean of the first and last three days did not differ by more than 5% from the six-day mean. Each tandem schedule was preceded and followed by a variable-interval schedule with a nominal reinforcement frequency equivalent to or slightly less (in the case of the tandem VI 60-sec FI 0.5-sec for all birds and preceding the tandem VI 60-sec FT 2-sec for Bird 87) than the associated tandem schedule. Each VI schedule was arranged so

Table 1

Sequence of schedules and number of sessions each schedule was in effect.

Condition	Schedule	Number of Sessions
	BIRD 87	
1.	VI 70-sec	17
2.	*tand* VI 60-sec FT 10-sec	33
3.	VI 70-sec	12
4.	VI 61-sec	12
5.	*tand* VI 61-sec FI 1-sec	23
6.	VI 61-sec	23
7.	*tand* VI 60-sec FT 0.5-sec	17
8.	VI 61-sec	18
9.	VI 64-sec	7
10.	*tand* VI 60-sec FT 4-sec	16
11.	VI 64-sec	6
12.	*tand* VI 60-sec FT 2-sec	36
13.	VI 62-sec	6
14.	VI 61-sec	9
15.	*tand* VI 60-sec FT 0.5-sec	8
16.	VI 61-sec	8
17.	*tand* VI 60-sec FT 1-sec	14
18.	VI 61-sec	10
19.	VI 64-sec	16
20.	*tand* VI 60-sec FT 4-sec	27
21.	VI 64-sec	6
	BIRD 39	
1.	VI 61-sec	31
2.	*tand* VI 60-sec FT 1-sec	23
3.	VI 61-sec	23
4.	*tand* VI 60-sec FT 0.5-sec	35
5.	VI 61-sec	24
6.	VI 70-sec	16
7.	*tand* VI 60-sec FT 10-sec	16
8.	VI 70-sec	14
9.	VI 64-sec	12
10.	*tand* VI 60-sec FT 4-sec	10
11.	VI 64-sec	20
12.	VI 61-sec	11
13.	*tand* VI 61-sec FT 0.5-sec	11
14.	VI 61-sec	9
15.	*tand* VI 60-sec FT 1-sec	13
16.	VI 61-sec	10
	BIRD 22	
1.	VI 61-sec	24
2.	*tand* VI 60-sec FT 0.5-sec	29
3.	VI 61-sec	19
4.	*tand* VI 60-sec FT 1-sec	42
5.	VI 61-sec	10
6.	VI 70-sec	16
7.	*tand* VI 60-sec FT 10-sec	14
8.	VI 70-sec	21
9.	VI 64-sec	10
10.	*tand* VI 60-sec FT 4-sec	9
11.	VI 64-sec	9
12.	VI 61-sec	8
13.	*tand* VI 60-sec FT 0.5-sec	29
14.	VI 61-sec	12
15.	*tand* VI 60-sec FT 1-sec	11
16.	VI 61-sec	16
17.	VI 61-sec	9
18.	*tand* VI 60-sec FT 4-sec	17
19.	VI 64-sec	10

that when a given interval programmed on a film-tape reader was completed, a timer set for the length of the delay for the corresponding tandem schedule was started. At the end of the timer operation, the next key peck was followed immediately by the reinforcing stimulus. During each comparable tandem schedule, the tape programmer, rather than starting the clock, allowed the next key peck to start the timer. At the end of the timer operation, the reinforcer was delivered independently of the subject's behavior. Sessions were conducted seven days a week and each lasted until 60 reinforcers were delivered.

A measure of actual (obtained) delays between the last key peck and each reinforcement was obtained by having the key peck that started the delay timer also start a second timer. Each subsequent peck during the delay interval reset this second timer. The delivery of the reinforcer then permitted the remaining time on the second timer to be recorded on a cumulative timer, from which the average delay per reinforcer was calculated.

RESULTS

Figure 1 shows the response rates of each bird during the first and last six sessions of each *tand* VI FT schedule and during the last six sessions of the VI schedule immediately preceding and following each tandem schedule. Solid lines separate VI from *tand* VI FT schedules and the dashed lines separate the first six and last six sessions of each tandem schedule. Data from individual birds are shown in the columns and the rows are different delay conditions. The designations "A" and "B" indicate the first and second exposure to a given delay.

Response rates usually decreased during the first few sessions of the tandem schedule, although there were exceptions (*e.g.*, Bird 87 during the first exposure to *tand* VI 60-sec FT 0.50-sec). This was followed by several sessions in which responding changed unsystematically and then stabilized. Generally, stable response rates were either higher than or not systematically different from the baseline conditions during the shorter delays. Longer delays resulted in systematic decreases in response rates. Response rates returned to approximately the previously established baseline levels when the VI schedules were reinstated after each tandem schedule.
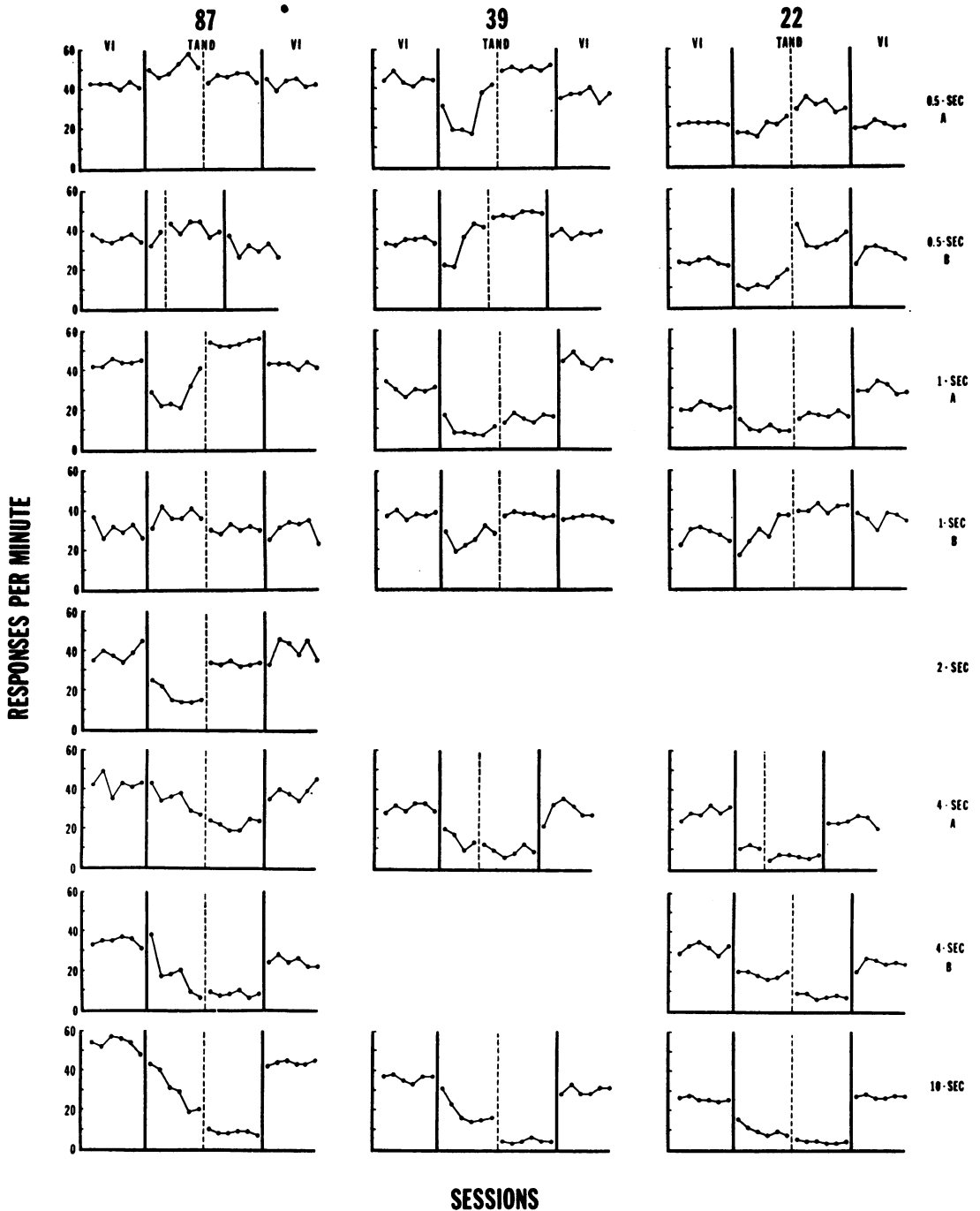
SESSIONS

Fig. 1. Responses per minute for each bird (columns) during the first and second exposure to each value of the *tand* VI 60-sec FT schedules. Each set of coordinates shows response rates during the first and last six sessions of each tandem schedule and the last six sessions of the VI schedule immediately preceding and following the tandem schedules as outlined in Table 1. Where the number of sessions at a given tandem schedule was fewer than 12, all sessions are presented. Values of the FT schedule are shown in the right margin. The designations "A" and "B" refer to the first and second exposure to a given tandem schedule.
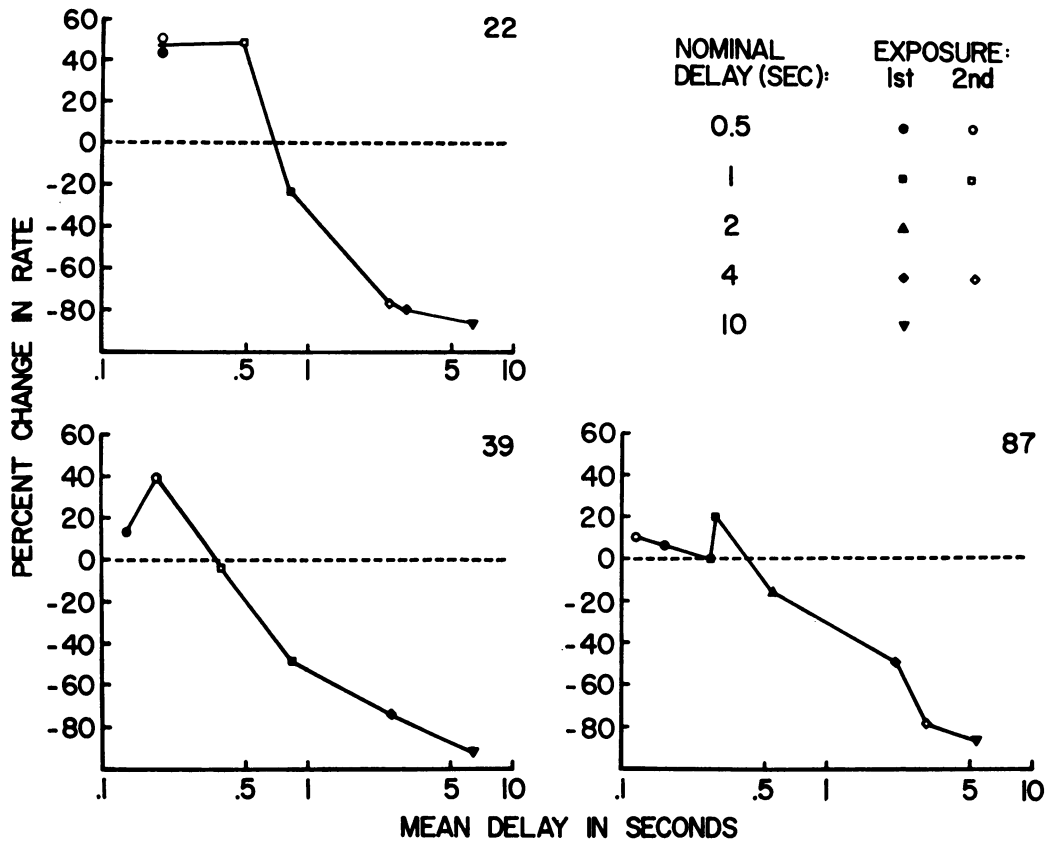
Fig. 2. Per cent change in mean response rate from the immediately preceding VI baseline for each delay (FT) value as a function of the obtained delay. The nominal delays (FT schedules) are shown by the different symbols. Data points were calculated from stable rates under each condition.

Figure 2 shows for each bird the relation between the mean percentage change in response rate from the preceding VI schedule and mean obtained delay for each tandem VI FT schedule. The nominal delays correspond to the FT schedule value. Responding increased relative to the preceding VI baseline at the shorter nominal delays and decreased monotonically with increasing delays.

For each tandem schedule and the preceding VI schedule, the difference in obtained reinforcement frequency was less than 2%. The exception to this was that, for Birds 22 and 87, there were reinforcement frequency changes from VI 70-sec to *tand* VI 60-sec FT 10-sec of 10% and 16% (from 0.84 reinforcers per minute under VI 70-sec to 0.72 and 0.76 reinforcers per minute under the tandem schedule). The reason for this decrease was that rates and/or patterns of responding changed in such a way that the FT schedule was not initiated by a

key peck as soon as its initiation was made available under the VI schedule.

DISCUSSION

The effects of an unsignalled delay of reinforcement arranged by tandem VI FT schedules were similar to those reported using other delay-of-reinforcement procedures, *i.e.,* the tandem-schedules procedures of the present study, procedures with unsignalled delay and a DRO schedule during the delay interval, and procedures with signalled delay of reinforcement all resulted in systematic decreases in responding with increasing delays (*cf.* Azzi *et al.,* 1964; Chung, 1965). With signalled delay procedures, changes in delay interval can be manipulated and controlled independently of rate, whereas with the present unsignalled delay procedures, rate changes and delays obtained are likely to covary. Thus, the data in

Figure 2 are an expression of correlation between two dependent variables and it is improper causally to attribute change in response rate to changes in obtained delays. However, the results do show clearly that nominal delays were functionally related to both of these dependent variables, *i.e.*, longer nominal delays produced both lower response rates and longer obtained delays.

By comparison with the present results, Williams (1976) did not find a reliable, systematic relation between responding and nominal delay duration during an unsignalled delay procedure. In his study, delays of 3, 8, and 15 sec were each in effect for only 10 sessions. Responding after 10 sessions of exposure to the delay conditions in the present study was frequently quite variable and this variability may in part account for differences between the present results and the unsystematic relation reported by Williams. Also, the data in Figure 1 show that the changes in response rates from the nondelay baseline at the 4- and 10-sec delays were not very different from one another and that asymptotic reductions in responding may be reached with unsignalled delays in the 4- to 10-sec delay range. The different delay values used by Williams may have produced equivalent obtained delays and/or the delay values he studied may have produced near-maximum response reductions.

Differences between nondelay and delay conditions in this experiment cannot be attributed to changes in reinforcement frequency which, in previous experiments, typically accompany the introduction of delayed reinforcement. With the exceptions noted, the frequency of reinforcement in each nondelayed baseline schedule and the subsequent delay condition were quite similar here. Of course, the frequency of reinforcement differed somewhat at the different delay values (*e.g.*, 0.5-sec delays *versus* 10-sec delay).

One effect of the short nominal delays (0.5 sec and, in some instances, 1.0 sec) was increased response rates relative to the nondelay baseline schedule. Chung (1965) found instances of facilitated response rates with short delays and suggested that with the short delay, the animal approaches the food hopper just before its being raised, thereby obtaining more food than under the nondelay condition. However, this explanation does not account for similar increases obtained in the present ex-

periment during the unsignalled delay procedure. One speculation is that increases may be an artifactual consequence of changes in the interresponse time (IRT) distribution. The tandem schedule specifies a maximum interval between a response and a reinforcer and, as a result, IRTs shorter than the value of the FT component value are selectively reinforced. Since pigeons' key-peck responses tend to occur in bursts during VI schedules, the response that initiates the delay interval is likely to be quickly followed by other responses that occur during the delay interval. The adventitious reinforcement of shorter IRTs could result in a shift in the IRT distribution toward shorter values and overall increases in rate. With longer nominal delay values, the likelihood of such bursts is not great and the reinforcement of shorter IRTs does not occur. This interpretation might also account for rate increases at short delays in the signalled delay procedure, insofar as bursts of responses might extend into the delay period.

The results of delay of reinforcement experiments are frequently cited as evidence of the importance of close temporal response-reinforcer contiguity, since longer delays generally result in lower rates of response. In these experiments, various procedures have been used to ensure that responding during the delay interval does not occur. As previously suggested, a DRO contingency (*e.g.*, Azzi et al., 1964) during the delay may artificially reduce response rates in the initial component. A blackout during the delay interval also may eliminate responding, but, again, it might be argued that behavior during the blackout may affect responding during the initial component (*cf.* Sadowsky, 1973). During the present tandem schedules, response-reinforcer contiguity was modified without the use of either a DRO contingency or blackout during the delay interval. Thus, the relation between rate and temporal contiguity shown in Figure 2 generally argues for the importance of temporal contiguity in the control of behavior (but see Williams, 1976).

The effects of unsignalled delay of reinforcement have been compared experimentally to the effects of response-independent reinforcement (Sizemore and Lattal, 1977; Williams, 1976). The present tandem schedules place a limit on the maximum delay between a response and a reinforcer, whereas schedules of

response-independent reinforcement do not. The effects of such limits on the maximum delay during the tandem schedules are similar to the finding (Lattal, 1974) that response rates are inversely related to the ratio of response-dependent reinforcers (nondelayed) to response-independent reinforcers. Varying this ratio changes both the response-reinforcer dependency and contiguity simultaneously. By comparison, changes in the maximum response-reinforcer delay interval created by the present procedure produced systematic changes in response rate while a constant response-reinforcer dependency was in effect.

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